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European Refuse Fired Energy Systems: Evaluation of Design Practices. Volume XVII: Baden-Brugg Plant, Turgi, Aargau, Switzerland

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The evaluation, which consists of two volumes of text and 15 trip reports, analyzes the experiences of the Europeans with waste to energy systems. The text is a compilation of the data obtained during visits to 15 major European refuse fired energy systems and visits to systems vendors, government agencies and other plants.

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EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

Baden-Brugg Plant
Turgi, Aargau, Switzerland

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Volume 17

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

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An environmental protection publication (SW-176c.17) in the solid waste management series.

TRIP REPORT

to

BADEN-BRUGG PLANT
TURGI, AARGAU, SWITZERLAND

on the contract

EVALUATION OF EUROPEAN
REFUSE FIRED STEAM GENERATOR
DESIGN PRACTICES

to

U.S. ENVIRONMENTAL PROTECTION AGENCY

September, 1977

EPA-Contract Number: 68-01-4376
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by

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ORGANIZATION

The four volumes and 15 trip reports are organized the the following fashion:

VOLUME I

A EXECUTIVE SUMMARY
B INVENTORY OF WASTE-TO-ENERGY PLANTS
C DESCRIPTION OF COMMUNITIES VISITED
D SEPARABLE WASTE STREAMS
E REFUSE COLLECTION AND TRANSFER STATIONS
F COMPOSITION OF REFUSE
G HEATING VALUE OF REFUSE
H REFUSE GENERATION AND BURNING RATES PER PERSON
I DEVELOPMENT OF VISITED SYSTEMS

VOLUME II

J TOTAL OPERATING SYSTEM RESULTS
K ENERGY UTILIZATION
L ECONOMICS AND FINANCE
M OWNERSHIP, ORGANIZATION, PERSONNEL AND TRAINING

VOLUME III

P REFUSE HANDLING
Q GRATES AND PRIMARY AIR
R ASH HANDLING AND RECOVERY
S FURNACE WALL
T SECONDARY (OVERFIRE) AIR

VOLUME IV

U BOILERS
V SUPPLEMENTARY CO-FIRING WITH OIL, WASTE OIL AND SOLVENTS
W CO-DISPOSAL OF REFUSE AND SEWAGE SLUDGE
X AIR POLLUTION CONTROL
Y START-UP AND SHUT-DOWN
Z APPENDIX

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PREFACE

This trip report is one of a series of 15 trip reports on European waste-to-energy systems prepared for the U.S. Environmental Protection Agency. The overall objective of this investigation is to describe and analyze European plants in such ways that the essential factors in their successful operation can be interpreted and applied in various U.S. communities. The plants visited are considered from the standpoint of environment, economics and technology.

The material in this report has been carefully reviewed by the European grate or boiler manufacturers and respective American licensees. Nevertheless, Battelle Columbus Laboratories maintains ultimate responsibility for the report content. The opinions set forth in this report are those of the Battelle staff members and are not to be considered by EPA policy.

The intent of the report is to provide decision making information. The reader is thus cautioned against believing that there is enough information to design a system. Some proprietary information has been deleted at the request of vendors. While the contents are detailed, they represent only the tip of the iceberg of knowledge necessary to develop a reliable, economical and environmentally beneficial system.

The selection of particular plants to visit was made by Battelle, the American licensees, the European grate manufacturers, and EPA. Purposely, the sampling is skewed to the "better" plants that are models of what the parties would like to develop in America. Some plants were selected because many features envolved at that plant. Others were chosen because of strong American interest in co-disposal of refuse and sewage sludge.

The four volumes plus the trip reports for the 15 European plants are available through The National Technical Information Service, Springfield, Virginia 22161. NTIS numbers for the volumes and ordering information are contained in the back of this publication. Of the 19 volumes only the Executive Summary and Inventory have been prepared for wide distribution.

SUMMARY

This plant has been a logical result of the environmentally conscious planning begun in 1956 by two communities in a highly industrialized but nevertheless very clean and picturesque area in northern Switzerland. The plant is small and the design approach was conventional, using about the best of the known available technology at the time for waste-to-energy systems. As a result, its operational problems have been minor and it is achieving its goal -- a highly acceptable operation environmentally with acceptable costs for disposal of community wastes while recovering some useful energy in the process.

The plant was preceded by a compost plant which began operation in June 1961, but by 1964, it became apparent that the plant could not handle a growing load of waste. Expansion of the plant would have overloaded the available markets for compost hence, after further study, a loan of 16.5 million Swiss Francs was obtained in May 1966, to build a 2-furnace heat-recovery plant. Steady operation began November 20, 1970.

There have been no major operational problems. Corrosion of a few of the water-tube-wall tubes and superheater have been caused by a combination of high gas velocities, inadequate gas mixing and excessive soot-blower concentration on a few tubes. These deficiencies have been or are being corrected by tube cladding, shielding and by improved mixing through better air distribution.

The net burning cost after considering operating, maintenance, repairs, financing and income from thermal and electrical output is now averaging about 50.23 Swiss Francs/tonne ($18.37/ton based on 2.48 Fr/$).

STATISTICAL SUMMARY

Baden-Brugg Plant

Community description:	
Area (square kilometers)	100
Population (number of people)	141,000
Key terrain feature	mountainous
Solid waste practices:	
Total waste generated per day (tonnes/day)	124.7 (365-day yr)
Waste generation rate (Kg/person/yr)	322
Lower heating value of waste (Kcal/kg)	2600
Collection period (days/week)	5
Cost of collection (local currency/tonne)	50 SFr
Use of transfer and/or pretreatment (yes or no)	No
Distance from generation centroid to:	
Local landfill (kilometers)	Landfill 30 km away but not used
Refuse fired steam generator (kilometers)	
Waste type input to system	mixed municipal refuse
Cofiring of sewage sludge (yes or no)	No
Development of the system:	
Date operation began (year)	November 1970
Plant architecture:	
Material of exterior construction	Concrete
Stack height (meters)	85.6
Refuse fired steam generator equipment:	
Mass burning (yes or no)	Yes
Waste conditions into feed chute:	
Moisture (percent)	Approximately 25 percent
Lower heating value (Kcal/kg)	2600
Volume burned:	
Capacity per furnace (tonnes/day)	100
Number of furnaces constructed (number)	2

Capacity per system (tonnes/day)	200
Actual per furnace (tonnes/day)	80-100
Number of furnaces normally operating (number)	2
Actual per system (tonnes/day)	160-200 (5 days/week)
Use auxiliary reduction equipment (yes or no)	No
Pit capacity level full:	
(Tonnes)	---
(m^3)	
Crane capacity:	2600
(tonnes)	5t (2 cranes)
(m^3)	2
Feeder drive method	Hydraulic
Burning grate:	
Manufacturer	Alberti-Fonsar
Type	Stepped reciprocating
Number of sections (number)	7 steps long
Length overall (m)	7.5
Width overall (m)	2.5
Primary air-max	
Secondary air-overfire air-max (m^3/min)	
Furnace volume (m^3)	66
Furnace wall tube diameter (cm)	7.61
Furnace heating surface (m^2)	892
Auxiliary fuel capability (yes or no)	Yes
Use of superheater (yes or no)	Yes
Boiler	
Manufacturer	Alberti-Fonsar
Type	Natural circ. water tube
Number of boiler passes (number)	3
Steam production per boiler (t/hr max)	12.5
Total plant steam production (t/hr max)	25.0
Steam temperature (^oC)	400
Steam pressure (atm)	40

Use of economizer (yes or no)	Yes
Use of air preheater (yes or no)	No
Use of flue gas reheater (yes or no)	No
Cofire (fuel or waste) input	No
Use of electricity generator (yes or no)	Yes
Type of turbine	Condensing
Number of turbines (number)	1
Steam consumption (t/hr)	25 (on completion)
Electrical production capacity per turbine (MW)	5.2
Total electrical production capacity (MW)	5.2
Turbine back pressure (kg/m^2)	---
User of electricity ("Internal" and/or "External")	Internal, external

Energy utilization:

Medium of energy transfer	Steam, hot water
Temperature of medium (^oC)	90-70 (water)
Population receiving energy (number)	
Pressure of medium (kg/m^2)	3.0/10.0
Energy return medium	Water

Pollution control:

Air:

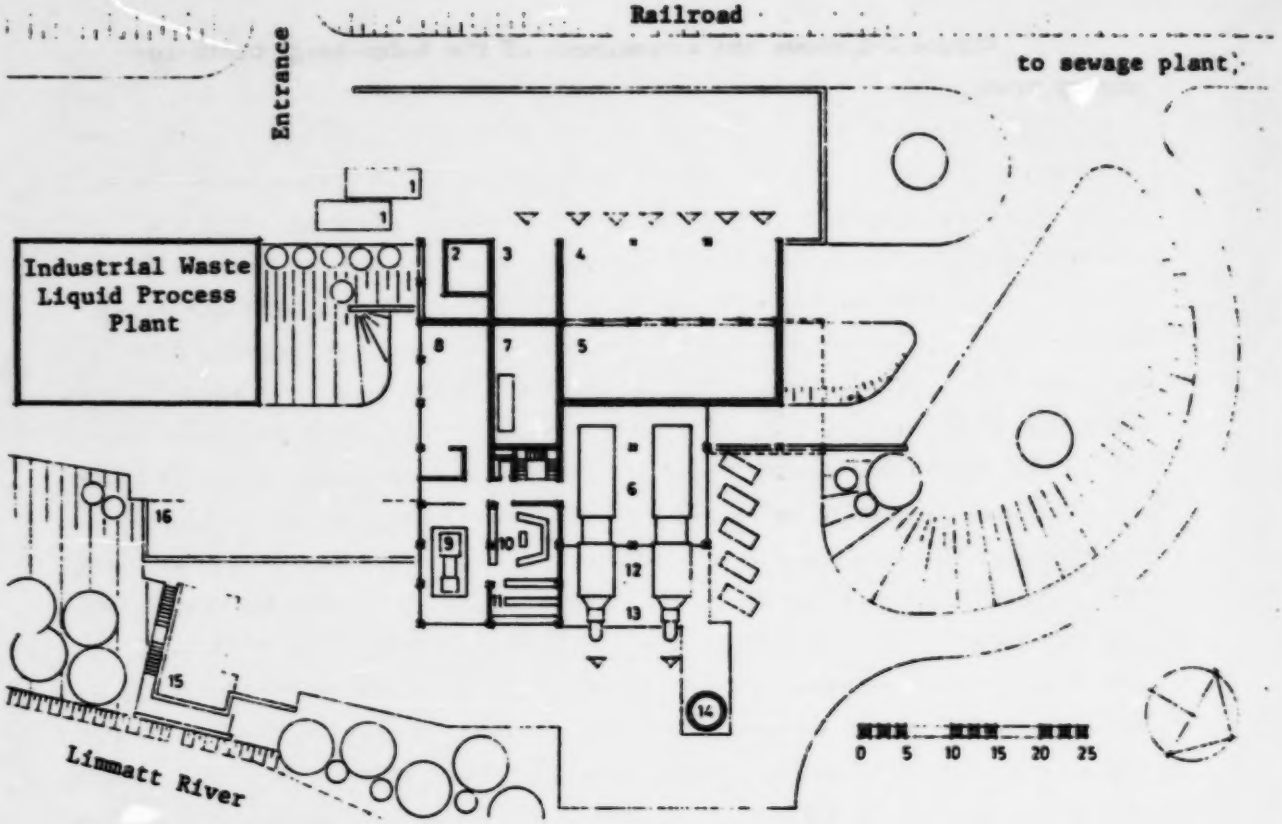
Furnace exit conditions

Gas flow rate (m^3/hr)	64,000 (max.)
Furnace exit loading (mg/Nm^3)	100 at 7% CO_2

Equipment:	
Mechanical cyclone collector (yes or no)	Yes
Electrostatic precipitator (yes or no)	Yes
Manufacturer	Elex
Inlet loading on precipitator (mg/Nm^3)	---
Exit - leading on precipitator (mg/Nm^3)	100 at 7% CO_2
Legislative requirement (mg/Nm^3)	100 at 7% CO_2
Scrubber (yes or no)	No
Inlet loading:	
H Cl (mg/Nm^3)	N.A.
H F (mg/Nm^3)	N.A.
Exit loading:	
H Cl (mg/Nm^3)	
H F (mg/Nm^3)	N.A.
Legislative requirements (mg/Nm^3)	N.A.
Other air pollution control equipment (yes or no)	No
Water:	
Total volume of waste water (liters/hr)	
Ash:	
Volume of ash (tonnes/day)	Approx. 57 (wet)
Volume of metal recovered (tonnes/day)	

OVERALL SCHEMATIC

Figure 2-1 shows the arrangement of the Baden-Brugg waste-to-energy plant.



1. Weigh scale
2. Scale office
3. Waste oil
4. Tipping area
5. Refuse bunker
6. Furnace room
7. Feedwater tank
8. Shop
9. Turbogenerator
10. Control room
11. Electrical controls
12. Electrostatic precipitator
13. Mechanical dust collector
14. Chimney
15. Reservoir
16. Garage

FIGURE 2-1. MAP OF BADEN-BRUGG PLANT
(Courtesy of Baden-Brugg Waste Management Association)

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DEVELOPMENT OF THE SYSTEM

In 1956 the separated communities of Baden-Brugg began a study of alternate methods for solving their growing solid waste problems (see Figure 2). This study envisioned by 1985 a population of 77,000 and a solid waste production of 20,000 tonnes (22,000 tons) per year. A common waste processing plant was recommended for the 2 regions. A compost plant at Turgi was recommended as a first step to be followed by an incinerator when needed.

In 1959 the Zweckverband Kehricht-Verwertung Region Baden-Brugg (Baden-Brugg Waste Management Association) was formed and included 8 other adjacent communities shown in Figure 2. The compost plant was begun in April 1960 and began operation in June 1961. However, this plant could not handle bulky and industrial waste. Also in 1964 it became apparent that the amount of waste was increasing and the population served was then up to 120,000. Preliminary plans envisioned an incinerator using 2 furnaces, each handling 100 tonnes (110 tons) per day based on refuse having a lower heating value of 2500 kcal/kg (4500 Btu/lb) [10,468 kJ/kg]. The local firm of Motor-Columbus, AG was engaged to study the feasibility of the plant which was to include heat recovery by steam and power generation plus the best available exhaust gas cleaning method. On the basis of this study in May 1966 a loan was obtained of 16.5 million Swiss Francs ($3.81 million at the 1966 exchange rate of 4.33). In the Spring of 1967 a boiler-furnace plant contract was agreed to with Alberti-Fonsar of Milan and at the end of 1967 a contract for the steam turbogenerator was given to the Baden firm of Brown-Boveri Company. Excavations were begun in February 1968, acceptance tests were begun in February 1970, the Association gave provisional acceptance in June 1970 and steady operation began November 20, 1970.

During the course of the development of the plant some opposition was voiced in the local press, partly because of expectations of air quality impacts on the hills across the river. The stack height was specified in the original RFP.

There were 5 bids, all very similar in price.

COMMUNITY DESCRIPTION

Geography

As shown in Figure 2-2, the plant is located in a narrow valley. The Limmatt River is on one side and a 2-track electric railroad is immediately against the other side of the plant. There are a few residences to the west but no concentrated landuse in the immediate vicinity. The population served is about 140,000.

A sewage treatment plant is located just North of the plant. Then just South of the plant, a privately operated hazardous waste treatment processes chemical wastes (arsenic, etc.) from all of Northern Switzerland. This is yet another example of the "Sanitary Park" so prevalent in Europe.

The area served (see Figure 2-3) is approximately 100 sq km (38.7 sq. mi.), about 18 km (11 mi) long and 5.5 km (3.4 mi) wide. There are 56 villages in the area. About 12 of these comprise original members of the Association, 44 other communities participate by sending waste.

FIGURE 2-2. VIEW OF BADEN-BRUGG 200 TONNE PER DAY PLANT FROM THE ADJACENT SEWAGE TREATMENT PLANT PROPERTY (Courtesy Baden-Brugg Waste Management Association)

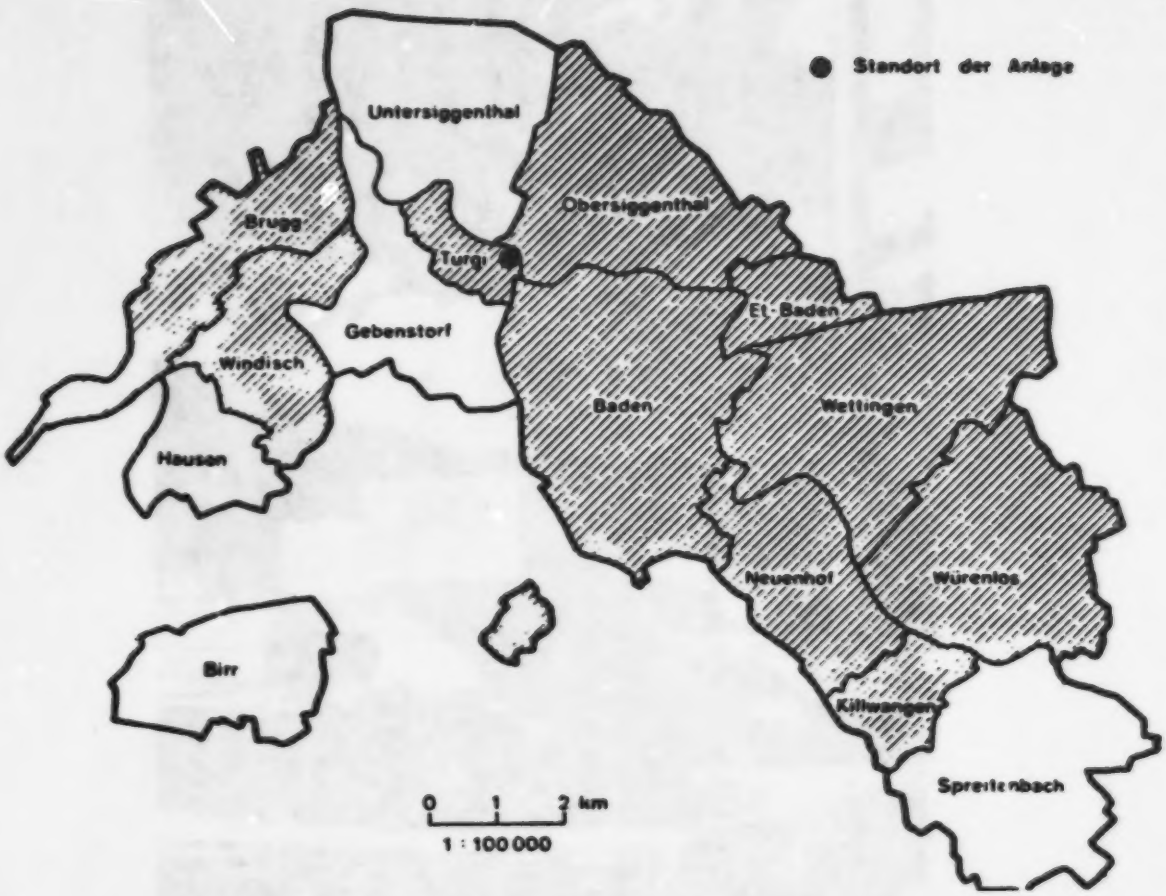

FIGURE 2-3. AREA IN AARGAU CANTON SERVED BY BADEN BRUGG PLANT

Government and Industry

Many industrial plants are located in the area served by this plant. The world headquarters of the Brown-Boveri Co., is in Baden very near to the plant. The engineering firm of Motor-Columbus is also in Baden.

SOLID WASTE PRACTICES

Solid Waste Generation

In Figure 2-4, it can be observed that the population served has increased by 40 percent since the plant started in 1970, because more communities joined. Also, the per capita waste generation rate increased. Thus the total waste collected increased 56 percent between 1971 and 1976. However, the rate of increase has been dropping since 1973.

Table 2-1 from the plant statistical statement, shows the waste categories and amounts processed in 1975 and 1976.

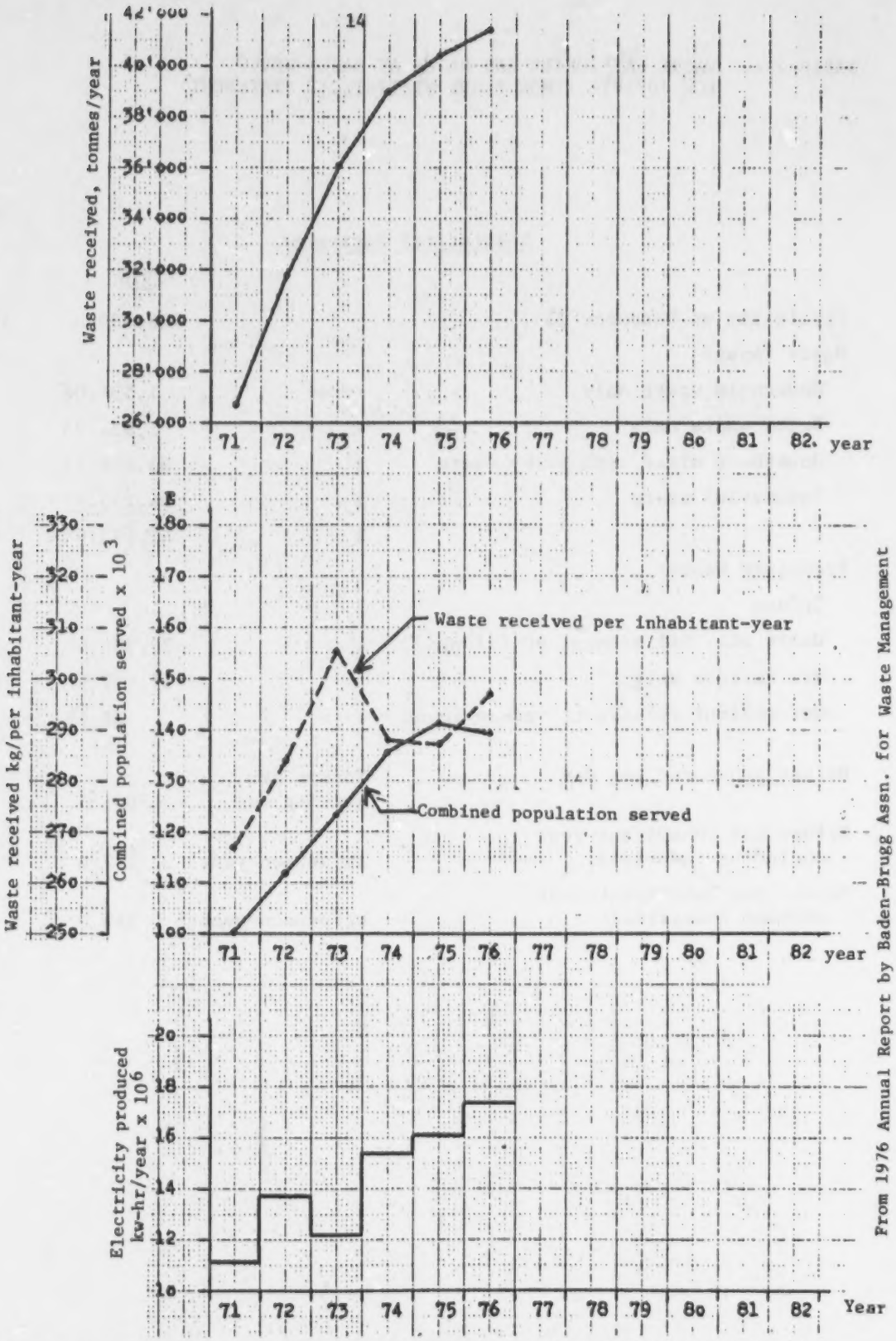

FIGURE 2-4. WASTE RECEIVED AND ELECTRICITY PRODUCED AT BADEN-BRUGG SINCE STARTUP

TABLE 2-1. WASTE CATEGORIES AND RATES AT BADEN-BRUGG FOR 1975-76 (FROM PLANT STATISTICAL STATEMENT)

Statistical Statement

		1976	1975
Population on December 31		139,300	141,000
Waste input:			
Household waste only	tonne	1,534.06	2,633.72
Bulky waste only	t	1,934.73	2,088.33
Household mixed with bulky waste	t	33,988.17	32,008.57
Industrial waste	t	4,235.99	4,152.17
	t	41,692.95	40,882.79
Processed Waste:			
Refuse			
Waste oil, oil sludge, emulsions	t	39,300.00	38,700.00
Wet residue weight	t	15,177.90	14,613.86
Wet residue related to refuse input	%	38.62	37.76
Refuse processed per day	Tonnes per working day	160.35	157.24
Refuse per inhabitant-year including industrial	kg/person-year	297.4	287.1
Refuse per inhabitant-year without industrial	kg/person-year	267.0	260.6

Solid Waste Collection Activities

About 35 percent of the waste glass generated is recycled through a pickup system for special containers at each residence. Some paper is gathered by Scouts.

There is no use of transfer stations nor of waste pretreatment.

About 60 public and 40 private collection vehicles bring refuse to eht plant 5 hours per day, 5 days per week. Each community is charged for the weight delivered by its trucks. Each family served pays 50-85 Sw Fr ($20-34) per year for collection.

Solid Waste Disposal

The grate residue is hauled 8 km, (5 miles) to a community landfill having the following characteristics:

type of landfill:	quarry
ownership:	community Würenlingen
costs (late 1977):	10.80 SF./m^3 ($3.30/$yd^3$ @ SF 2.5/$)
method of filling:	truck plus levelling with caterpillar
frequency of cover:	no cover

TOTAL OPERATING SYSTEM

Table 2-2 from the plant statistical statement shows the energy production figures for 1975 and 1976. The average plant evaporation rate for 1976 was 2.26 tonne steam per tonne refuse. Assuming the average LHV of the refuse was 2285 kcal/kg (9567 kJ/kg)[4113 Btu/lb] this corresponds to an average steam generating efficiency of 55 percent.

The electrical energy produced averaged 440 kwh/tonne. This corresponds to a generating efficiency of 16 percent.

The amount of thermal energy supplied to the adjacent plants was small and was not recorded.

The volume reduction of the refuse was estimated to be about 85 percent. The weight reduction achieved is about 37-38 percent.

The plant, which began operation in November 1970, has had no major shutdowns since the initial problems with tube wastage in 1973 after 11,000 hours operation. Normally, maintenance can be done during the regular week-end shut-down. Every 6 months the plant is down for 1 week for major overhaul.

Except for the routine downtime, operation was 99.1 percent of the time in 1975 and 96.7 in 1976.

PLANT ARCHITECTURE AND AESTHETIC ACCEPTABILITY

This small plant is formed basically of simple concrete forms but is impressive and attractive as located adjacent to the sewage treatment and Fairtec industrial waste treatment plants. These 2 small plants are crowded together in the narrow valley between a double-track railroad and the Limmat River but the combined appearance is good and not severely crowded.

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TABLE 2-2 ENERGY GENERATION RATES AT BADEN-BRUGG FOR 1975 AND 1976 (FROM PLANT STATISTICAL STATEMENT)

		1975	1976
Operating time of both furnaces	h/ year	10,598	9,750
Operating time of turbine	h/ year	6,132	5,467
Average furnace capacity	mt/h	3.72	3.97
Average boiler capacity	mt/h	8.41	8.60
Average turbine capacity	kw	2,833.2	2,943.0
Average coefficient of evaporation	t/t	2.26	2.16
Average heat value of waste	kcal/kg	2,285	2,165
Electrical energy per tonne of waste	kwh/mt	440	415
Total electrical production	kwh x 10^6	17.37	16.09
Electricity supplied to AEW, ARA, Fairtec ARA, Fairtec	kwh x 10^6	14.85	13.79
Electricity internally generated and used	kwh x 10^6	2.52	2.30
Electricity purchased from AEW	kwh x 10^6	0.20	0.20
Total internally used electricity (without losses)	kwh x 10^6	2.72	2.50
Electricity consumption per tonne of refuse	kwh/mt	68.91	64.44

REFUSE-FIRED STEAM GENERATOR EQUIPMENT

Both public and private trucks deliver refuse to the steam-generating plant 5 days per week. They are weighed on a Toledo scale which prints total, tare and net weights on a card. The scale is inspected once per year. An increasing amount of waste oil is received. In 1976 the waste oil totalled 172 tons for the year. Figure 2-5 shows the tipping area, waste oil receiving scale and indoor weighing station.

Originally the plant was equipped with a Hazemag hammermill shredder adjacent to the refuse pit to break up bulky refuse. However, in 1972 owing to the need to replace the shredder bars and re-weld the hammers every 3 months, the receipt of bulky wastes was limited to a maximum size of one meter. The homeowner is required to break up any objects larger than one meter on a side or to send large metal objects directly to a scrap dealer. The shredder is now operated only occasionally to assure that its working parts are kept in operable condition.

Figure 2-6 shows a truck delivering a load. After each truck driver delivers a load to the pit he is expected to clean his dumping area. The crane operator can direct truck drivers to alternate tipping bays by the red and green lights above the truck entrance (see Circle in Figure 2-5).

The refuse pit storage capacity when level-full is 2600m^3. Assuming a stored refuse density of 0.4 tonnes/m^3 (560 lb/yd^3) its storage volume would be 1040 tonnes (945 tons), or about a 5-day fuel supply at capacity operation. The pit is 23.4m (76.7 ft) long, 14.1m (45.3 ft) deep and 8.4m (27.6 ft wide). Fires in the pit can be controlled by means of overhead sprinklers.

The pit is equipped with 2 cranes built by Mars-Uto of 5-tonne capacity each. Each is equipped with a 2m^3 (2.6 yd^3) polyp or orange-peel type of grab. The weight of each crane load can be observed by the crane operator on a digital read-out actuated by a strain gage on the crane cable. The operator, whose pulpit is at the end of the pit, records this weight reading manually. Figure 2-7 shows the operator and two crane grabs.

An automatic crane stop is provided so that if the crane approaches an open delivery door on the side of the pit the crane is prevented from striking and damaging the open door.

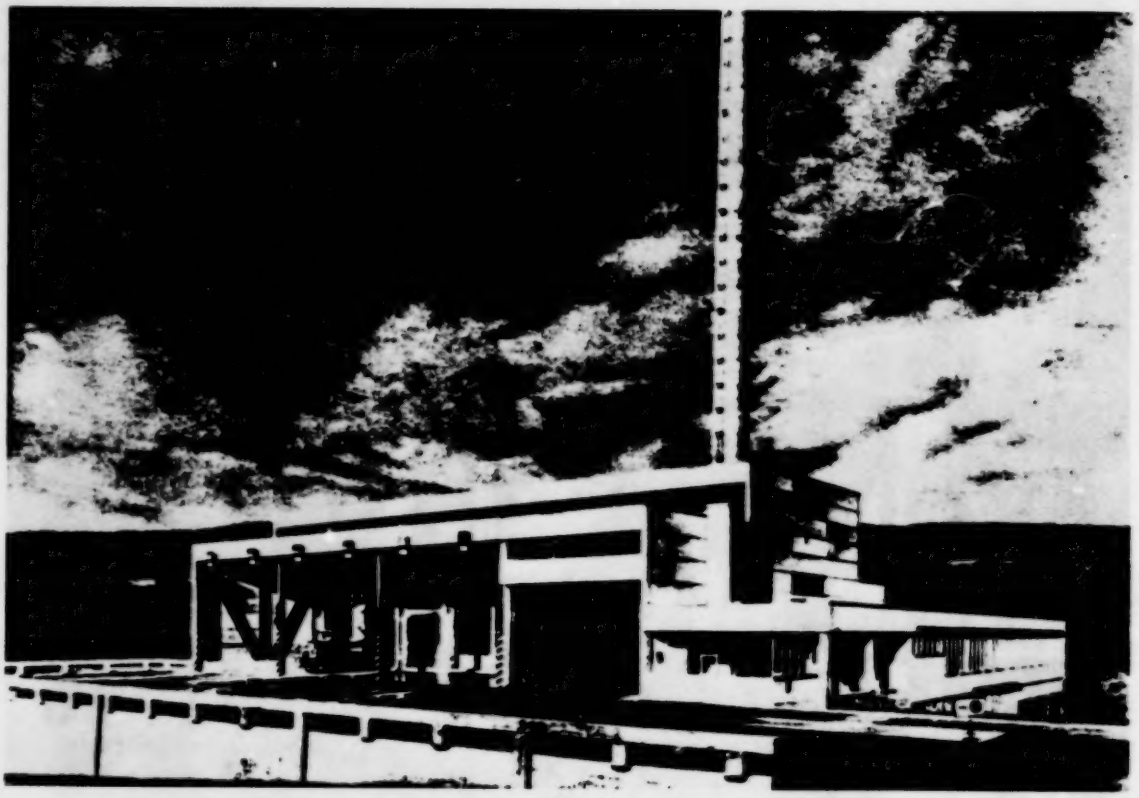

FIGURE 2-5. TIPPING AREA, SCALE ROOM, AND OFFICE ENTRANCE AT BADEN-BRUGG PLANT (Courtesy Region of Baden-Brugg)

FIGURE 2-6. TRUCK DELIVERING WASTE TO THE PIT AT BADEN-BRUGG. THE PIT DOORS ARE HYDRAULICALLY OPENED. (Courtesy Region of Baden-Brugg)

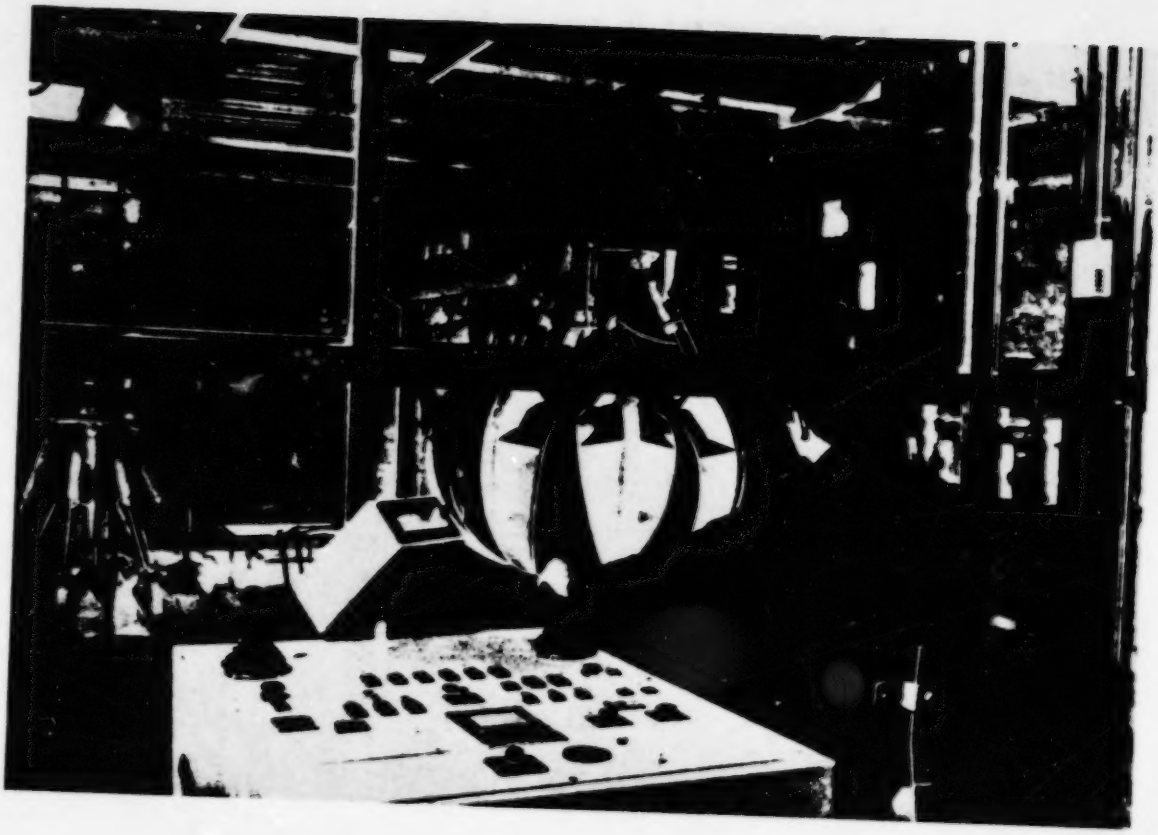

FIGURE 2-7. CRANE OPERATOR, CRANES AND GRABS ABOVE PIT
(Courtesy Region of Baden-Brugg)

The plant staff feel that it is beneficial to the operation to mix and store the refuse in the pit for at least 48 hours for the following advantages:

1. a more nearly homogeneous charge results
2. the material is more compact
3. fermentation raises the waste temperature which helps slightly with ignition
4. moisture content is more uniform.

All of these factors contribute toward better furnace operation.

In 1978 it is planned to begin 7-day per week operation of the plant.

Furnace Hopper and Feeder

The top of each furnace hopper is 4m (13.1 ft) square and the feed chute is 2.5m by 1.5m (8.2 ft by 4.9 ft). The chute is not cooled but insulated. If burnback into the hopper occurs it can be stopped by means of a hinged insulated cover placed over the hopper. When large objects jam the chutes a wood ram held by the grab is used to force the object downward.

A single level, hydraulically-driven ram feeder made by Hydron feeds the refuse inward every 1.5 min. The length of stroke is 600mm (1.9 ft). The speed of the motion is fixed. If something prevents the ram from withdrawing from the furnace an alarm sounds. Reliability has been essentially 100 percent. There is no feeder redundancy. After 7 years operation the cylinder on the drive has recently been replaced. The piston guide is lubricated once per month.

Initially the feeder piston seal leaked. That defect was corrected. The feeder plate was changed from cast iron to steel because early in the operation, heavy objects falling from the feed chute broke the feeder plate.

Burning Grate

Figure 2-8 shows an example of the Alberti-Fonsar GMP-7 stepped grate. At Baden-Brugg it is made up of 6 sections which provides an average fuel bed slope of about 24°. It was fabricated in Italy by the Fonderie e'Officine di Saronne S.p.A. using a grate material which is 25-30% chromium, 4% nickel, 0.5% manganese and 0.8% silicon. The grate is made up of steps which alternately are fixed and reciprocating. The reciprocating parts have a maximum stroke of 380mm (15 in) with the normal stroke being 350mm (14 in) which occurs about once every 2 minutes. As the upper step moves forward it tends to tumble the burning refuse downward to the next step, thus providing gentle agitation. Grate temperature can be monitored by the control room operator from indicators connected to three thermocouples located under the grate. The temperature is controlled to less than 400°C by control of primary air flow and feed rate.

The grate sections were guaranteed for 16 months. The manufacturer expects the grate to last 5 to 10 years. Some problem has been encountered with pluggage of the air holes in the grate by fused aluminum and plastics. When this happens, workmen wearing heavy wetted asbestos suits enter the partially cooled chamber to remove or punch through the fused material in the grate holes.

The grate residue is dropped when hot from the end of the grate into a large concrete quench tank which appears as a shallow slag basin in the lower part of Figure 2-10. At the deepest point, the water in the basin is 1.7 m (5.57 ft) deep. Residues from the precipitator and boiler passes are also dropped into this tank. The quenched residue settles to the bottom of the tank from which it is removed continuously by a 12 m (39 ft) drag-chain conveyor which drops it into a slag skip.

The manufacturer believes that they have since evolved at other plants a much better quench-tank removal device involving a piston-driven swing gate which tends to compress the residue as it lifts it much more nearly vertically otu of a much smaller, curved-bottom steel tank. As a result, the discharged residue is said to have only 25 percent moisture as against 40 percent from the system at this plant. The newer system also costs less and produces less waste water.

The wet residue is trucked to a landfill for which the dump charge has been SF, 43.5 per 7 m^3 container, equivalent to SF 6.2 per m^3 ($2.8/$yd^3$). In late 1977 it was raised to SF 10.80/m^3.

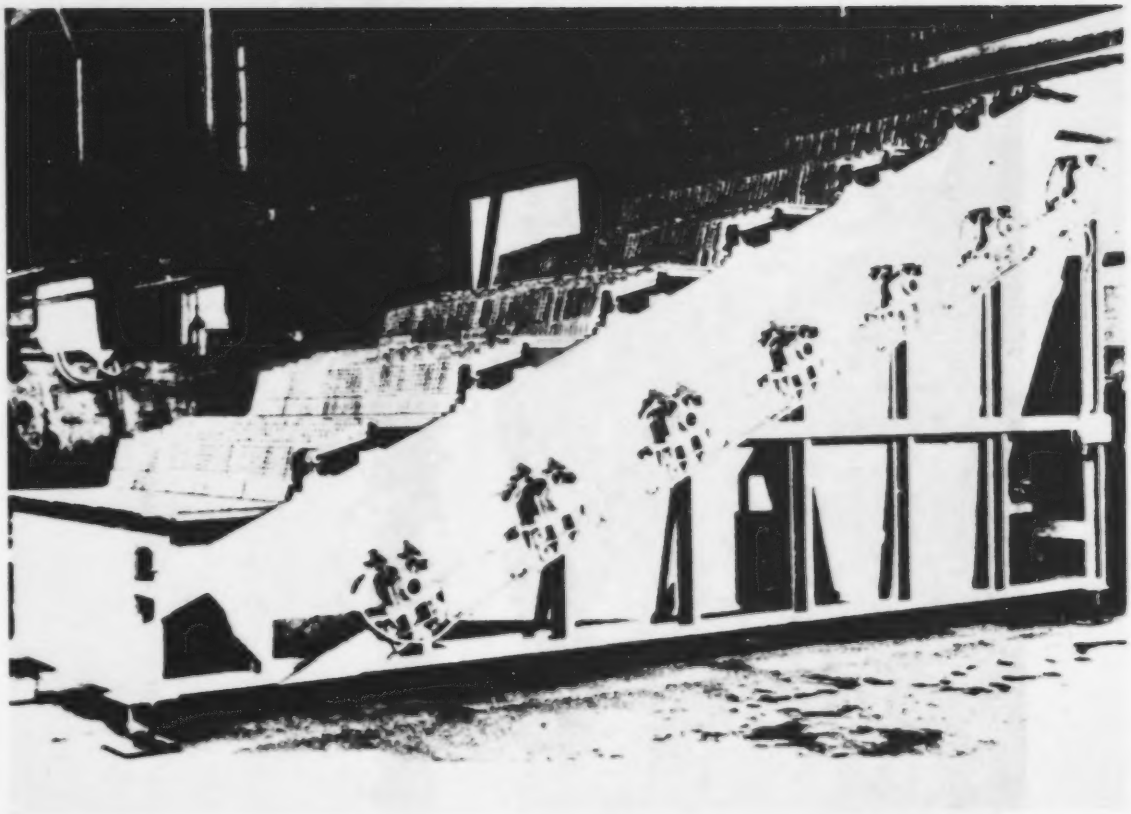

FIGURE 2-8. AN EXAMPLE OF THE ALBERTI FONSAR STEP GRATE SYSTEM ASSEMBLED AT THE FACTORY (Courtesy of Widmer + Ernst (Alberti-Fonsar))

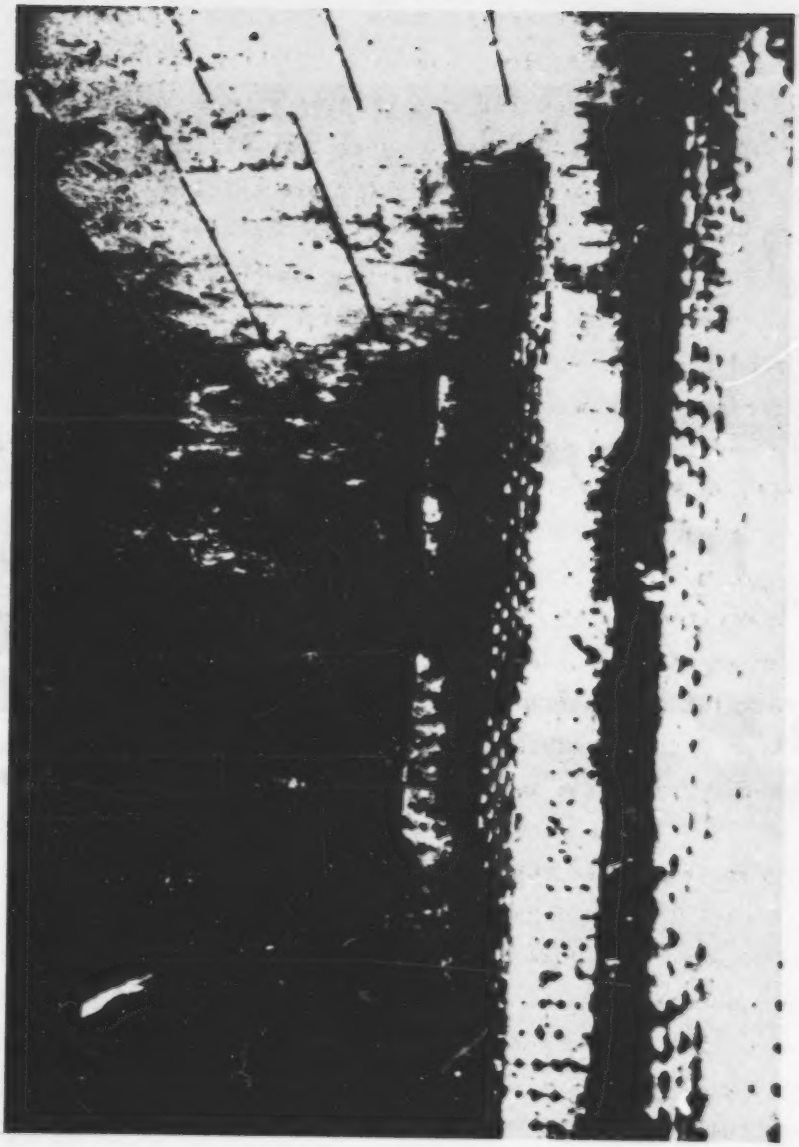

FIGURE 2-9. BADEN-BRUGG FURNACE GRATES (Battelle Photograph)

Furnace Wall (Combustion and First Pass Radiation Chambers)

The main furnace is largely refractory walled. Only the sloping rear wall of the furnace is water-cooled. Owing to successful experience in other plants these two furnaces are in process of being modified to incorporate air-cooling. The sidewalls of the furnace up to now have consisted only of Plibrico Super AB plastic refractory 150 mm (6 in) thick backed up by 250 mm (10 in) of high temperature calcium silicate insulation plus a 4 mm steel casing. The front arch is similarly all refractory except for a small water-cooled casting which protects the top-front corner of the furnace from the abrasive action of the refuse as it emerges from the feed chute into the furnace. A major portion of the refractory wall near the grate will soon be replaced by cast iron, air-cooled wall blocks developed by Künstler. These will also introduce some air formerly introduced by the original sidewall overfire (secondary) air jets shown in three separate horizontal rows in Figure 2-10 about one meter (39 in) above the grate. (See later section on tertiary air.)

As the combustion gases rise out of the partially cooled refractory walled furnace they are accelerated into a tall, open, vertical, water-tube walled boiler pass which is about 7 m (23 ft) tall, 2.5 m (8.2 ft) wide and 1.5 m (4.9 ft) deep. Thus its cross-sectional area is 3.75 m^2 (40.2 ft^2). Assuming a uniform flow and a gas temperature entering this first pass of about 1000 C (1832 F) and a gas flow rate of 5 kg/sec corresponding to 100 tonnes per hr and approximately 100% excess air, the entering velocity would be about 5 m/sec (16.4 ft/sec). This is considered a high velocity and, because of the eddies formed when the gases accelerate into this pass, this rather high velocity may have been partly responsible for early failure of 9 wall tubes in the lower part of this first pass.

As a result of those failures a 25 mm (1 in) silicon carbide covering was added over the lower 5 m (16 ft) of these walls. However, this increased the superheater outlet temperature 20 C (36 F). Hence in 1974, in Boiler No. 1 the height of this covering was reduced to only 1 m (3.28 ft). The silicon carbide covering is not held in place by welded studs but by 20 mm dia steel coils which are anchored to the tubes before being buried by the plastic refractory covering. Since this coil-supported covering was applied there have been no further failures of wall tubes. The wall covering now needs

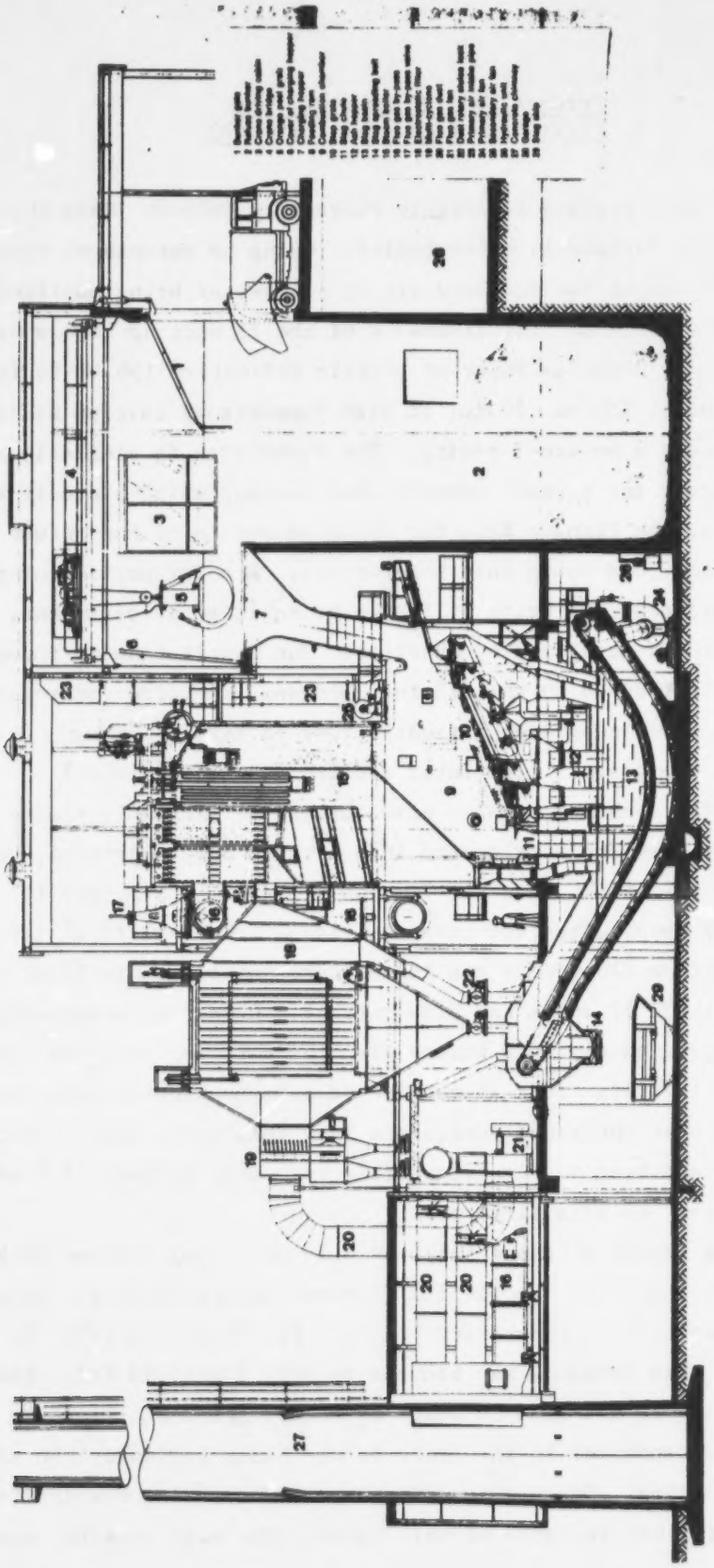

FIGURE 2-10. CROSS SECTION OF BADEN-BRUGG PLANT
(Courtesy Widmer + Ernst)

patching about every 3 to 7 years. Although this steel coil support for the refractory covering has apparently served well in this installation, the manufacturer has since used the more conventional welded steel studs to support the refractory covering on the sloping rear wall of the main furnace.

Figure 2-11 shows a steel coil used to reinforce the refractory coating on some wall tubes.

The manufacturer believes that the failure of 9 wall tubes was caused primarily by reducing gases flowing against those tubes. The tube material is C14UN15462-64, a typical carbon steel. They are 57 mm (2.24 in) dia with 2.9 mm (0.11 in) wall thickness and are spaced 59 mm on centers. (Regarding the subject of reducing gases see later section on Secondary Air.)

FIGURE 2-11. MR. LOCHLIGER, ASSISTANT PLANT MANAGER, HOLDING STEEL REINFORCING COIL FOR TUBE-COVERING MOLDED REFRACTORY (Battelle Photo)

Superheater

As the gases reach to the top of the first boiler pass they are turned 180 degrees and then pass downward through the second water-tube walled pass which contains The Superheater. It has a total heating surface of 104 m^2 (1119 ft^2). Final steam temperature is 400 C (752 F). The superheater tubes are vertical and are suspended from the top. They are 4 m (13 ft) long, 33.7 mm (1.32 in) dia. and are spaced on 120 mm (4.7 in) centers. The superheater steel is 14% chromium, 3% molybdenum. At first they were 2.9 mm (0.11 in) thick. Later the thickness was increased to 3.2 mm. Now they are 4 mm (0.15 in) thick. The final thick walled tubes were installed in Boiler No. 1 in 1972 and in Boiler No. 2 in 1974.

Although the gas flow through the superheater is mainly parallel flow, the horizontal entry of the gases into the superheater from the first pass is actually cross flow. Thus the hot gas, at a temperature of 700 C (1292 F), carrying potentially erosive and corrosive flyash, impinges against the 23 vertical superheater tubes in the first row. Initially this caused some tube wastage and the first row of tubes was replaced in 1972. Figure 2-12 shows the longitudinal failure of a Baden-Brugg first row superheater tube. Accordingly, in October 1973, after 11,290 hours of operation of Boiler No. 1, half shields made of Sicromal (18-8) steel tubing (see Figure 2-13) were clamped over the leading face of this first row only. Thicker walled superheater tubes have also been installed and additional 17,810 hours had been achieved at the time of our visit on May 9, 1977. The shields must be replaced about every 6000 hours. The plant management estimates that the present superheaters will last 60,000 hrs.

Although steam-actuated soot blowers are available for cleaning ash deposits from the superheater tubes they are not used because of the widespread experience that soot blowers often accelerate tube wastage. These superheaters are cleaned manually every 6 weeks, on weekends, by means of compressed air nozzles which can be inserted through the access doors in the wall of the superheater passage.

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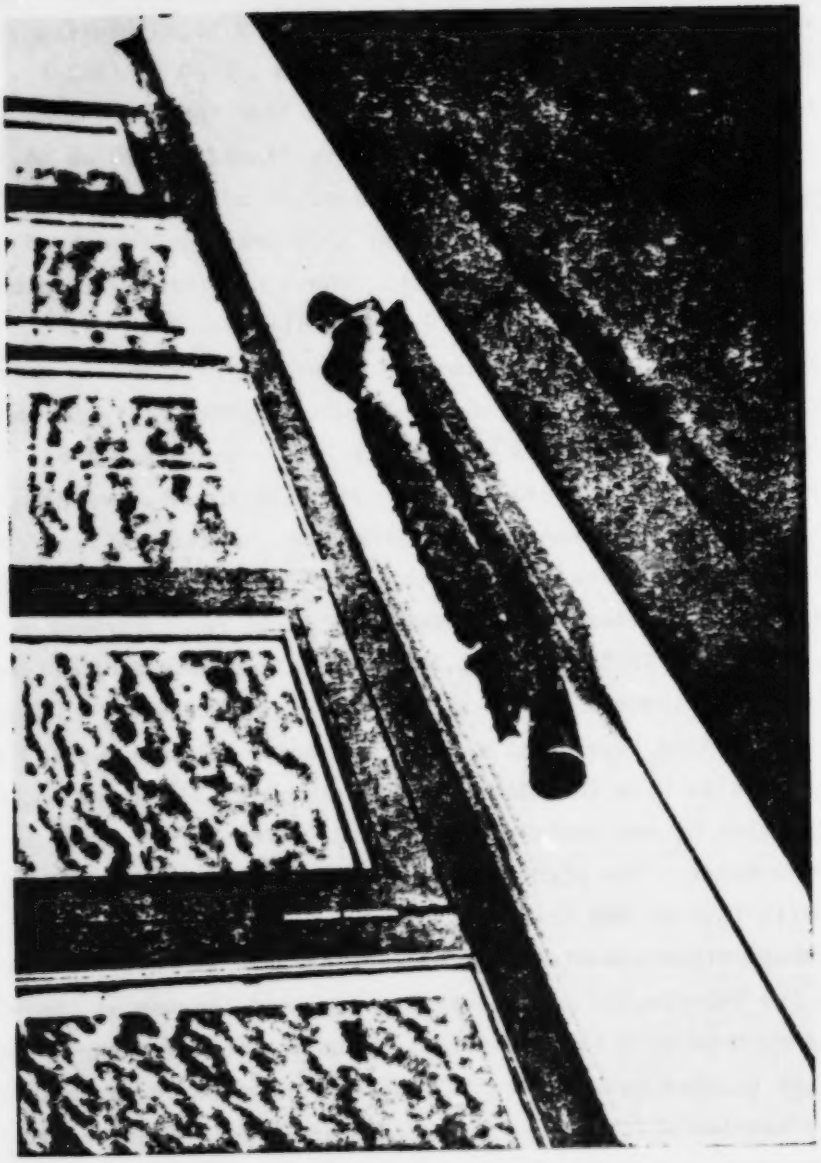

FIGURE 2-12. BADEN-BRUGG RUPTURED FIRST ROW SUPERHEATER TUBE (Battelle Photo)

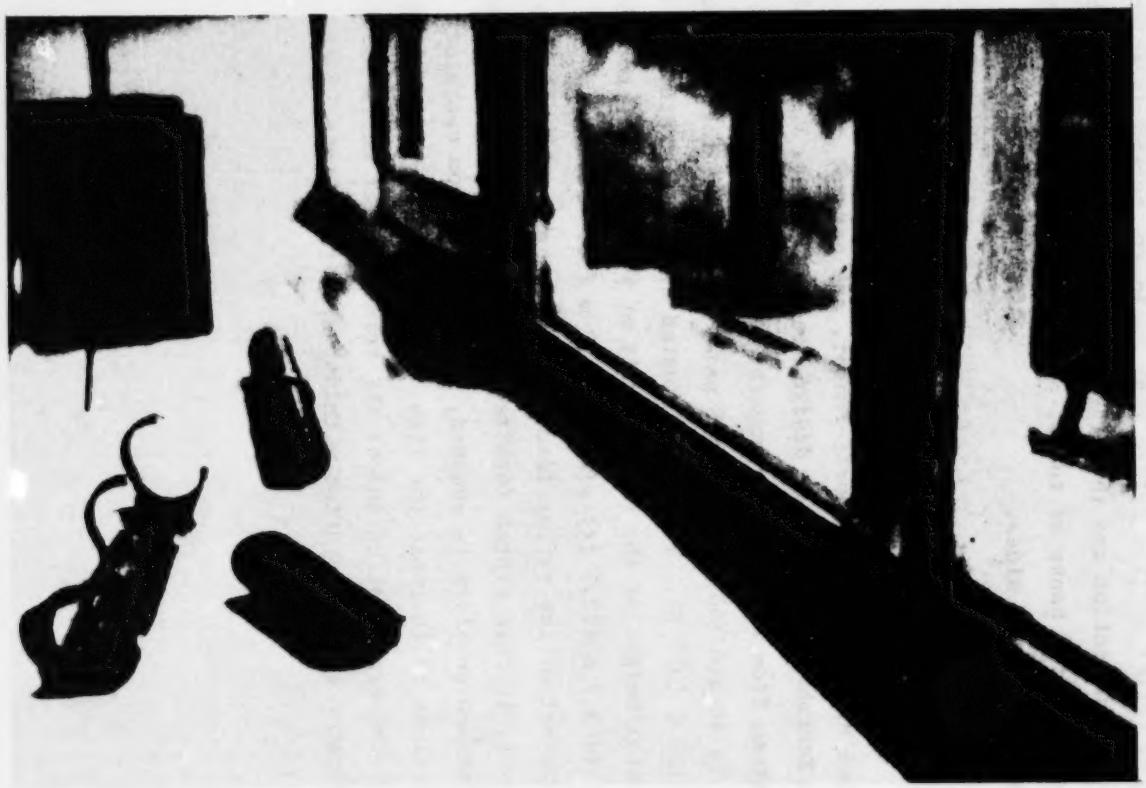

FIGURE 2-13. BADEN-BRUGG HALF SHIELDS FOR CLAMPING ON SUPERHEATER LEADING FACE (Battelle Photo)

Boiler (Convection Section)

Referring again to Figure 2-10, the gases are flowing downward as they leave the vertical superheater and then continue downward through a short open water-tube-walled boiler section before they again are turned upward to enter the boiler convection section and then the economizer. The boiler tubes are inclined and consist of 2 banks of tubes, one above the other and surrounded by water-tube walls on both sides.

Boiler (Overall)

The boilers, built by Alberti-Fonsar, are natural circulation type built under the Eckrohr (corner tube) design licensed by Dr. Vorkauf of Berlin. Their nominal steam flow rate is 13 tonnes/hr each (28,600 lb/hr). The steam pressure is 40 atm (40.53 bar) (588 psia), corresponding to a saturation temperature of 150 C (302 F). Final superheated steam temperature is 400 C (752 F). The total height of the boiler is 14 m(46 ft) above the boiler room floor. It is 3.7 m (12.1 ft) wide and 6.2 m (20.3 ft) deep.

The control of the refuse feed rate can be automatic from boiler pressure. However, if this system results in the overheating of a temperature sensor in the furnace an alarm is sounded, the control room operator is under instructions to increase the flow of secondary air and to reduce the frequency of the grate motion and of the refuse feeder until the furnace temperature indicator shows operation within a specified limit

Economizer

The economizer is divided into 2 vertical passages. Both are directly above the boiler convection section. The gases flow upward from the convection section into the first economizer pass, then turn 180 degrees and flow downward through the second pass. From there the gases go either to the precipitator or to a bypass which leads directly to the chimney.

The economizer tubes are 33.7 mm (1.33 in) dia, 2.9 mm (0.114 in) thick and both sections provide a total heating surface of 250 m^2 (2691 ft^2). Each economizer pass is 3 m (9.84 ft) wide, 1.2 m (3.93 ft) deep and 4.1 m (13.45 ft) high. The tubes are made of carbon steel (designated 35.8 II).

There have been no problems with economizer performance. Its expected life is at least 20 years.

Heat Release Rate

The nominal design loading of the grate is 238 kg/m^2-h (48.8 lb/ft^2-h). For an LHV of 2600 kcal/kg (10,8861 kJ/kg) [4680 Btu/lb] this corresponds to a heat release rate of 618,000 kcal/m^2-h (227,860 Btu/ft^2-hr). This is a very conservative full-load burning rate. Even at the maximum furnace rating of 120 tonnes/day, if the grate is 7.5 m long and 2.5 m wide (18,75 m^2) (201.8 ft^2), the burning rate is 266 kg/m2-h (54.6 lb/ft^2-h) corresponding to a heat release rate of 691,600 kcal/m^2-h (255,528 Btu/ft^2-h). These are also fairly conservative burning rates.

The volume of the main furnace plus the lower portion of the first open boiler pass where combustion is completed was stated by the manufacturer to total 66 m^3 (2330 ft^3). Considering the above heat release rates to occur in this volume the corresponding volume heat release rate is 196,477 kcal/m^3-h (22,080 Btu/ft^3-h) which is a moderate rate.

Plant Operation

Table 2-3 is a summary of weekly plant operating data for the 9 weeks May 2, 1976 to July 4, 1976, provided from routine plant records. The annual data similar to portions of this table will be discussed in later sections of the report. It is shown together here to facilitate the readers analysis of processing and production rates. It is of interest that the total waste burned never quite reached the nominal plant capacity for a 5-day week: 1000 tonnes. However, it nearly attained that rate in almost half of the weeks. But the maximum power generation rate of 3.5 mw was well below the nominal generator capacity of 5.2 mw. The cause of this reduction was not determined.

The evaporation rate, tons steam per ton of waste was normal and ranged from 2.16 to 2.66. The calculated heat value of the refuse 2115 to 2598 kcal/kg (8855 kJ/kg to 10,877 kJ/kg) [3807 to 4676 Btu/lb] also appears to be typical of European waste.

TABLE 2-3. BADEN-BRUGG WEEKLY OPERATING SUMMARY MAY 2 to JULY 4, 1976

		Week of the Year 1976								
		19	20	21	22	23	24	25	26	27
Amount of Waste Received Tonnes	t	817.21	803.37	871.37	720.82	993.13	767.00	685.64	798.64	765.14
Waste Burned-Furnace 1	t	472.83	439.54	469.94	300.63	482.13	382.84	453.38	433.75	406.70
" " " 2	t	468.43	446.99	476.15	300.37	472.28	370.94	451.08	-	417.20
" " " Total	t	941.26	886.45	946.09	601.00	954.41	753.78	904.46	433.75	823.90
Amount of waste oil received	t	0.68	-	-	-	2.04	0.84	1.26	1.32	0.58
Furnace residue, wet	t	358.96	332.74	347.84	274.76	368.14	309.02	354.34	204.72	279.18
Furnace 1, operating time	hr	127	123	123	78	126	100	124	125	124
" 2, " "	hr	126	124	122	78	126	101	124	-	124
Turbine operating time	hr	123	121	119	75	123	97	121	119	122
Electricity delivered to the network	kw/hr	356025	319650	308700	187125	318300	263100	321000	118050	326325
" consumed from the network	kw/hr	12975	19725	17850	34725	24300	15375	17325	18000	16500
" produced	kw/hr	442000	411000	401000	248000	410000	336000	415000	188000	420000
" consumed internally	kw/hr	65500	66900	64000	45800	65700	52600	66700	43300	65000
" to sewage plant from network	kw/hr	9000	14000	14000	31000	13000	11000	12000	13000	13000
" " " " " this plant	kw/hr	25900	31400	33000	16700	37300	25800	32800	30700	32100
Total electricity to sewage plant	kw/hr	34900	45400	47000	47700	50300	36800	44800	43700	45100
Process water	m^3	22	29	21	9	24	22	24	31	27
Cooling water	m^3	167	162	167	197	174	165	249	226	279
Total water consumption	m^3	189	191	188	222	198	187	273	297	306
Electrical consumption/ton waste	Wh/tK	470	464	424	413	430	446	459	433	510
Calculated heat value of refuse	kcal/kg	2344	2354	2147	2128	2115	2235	2230	2538	2598
Average generation rate	kw	3593	3397	3370	3307	3333	3464	3430	1580	3443
Average furnace burning rate	t/h	3.85	3.66	3.86	3.85	3.79	3.75	3.65	3.47	3.32
Average boiler steaming rate	t_D/h	8.92	8.64	8.48	8.38	8.20	8.57	8.59	8.37	8.82
Steam production ratio	t_D/tK	2.40	2.40	2.20	2.18	2.16	2.29	2.35	2.40	2.66

Boiler Water Treatment

The boiler water is treated by ion exchange using a system installed by Theodor Christ AG of Basel and having the following specifications:

Cationic Resin:

Pressure	3-6 atm
Maximum flow rate	3 m^3/hr
Quantity treated with each regeneration	48 m^3
Resin type	Amberlite IR 120
Resin quantity	380 liters
Regenerating acid flow rate	2.5 m^3/hr
Amount of 30% HCl per regeneration	95 kg 85 liters

Anionic Resin

Pressure	3-6 atm
Maximum flow rate	3 m^3/hr
Quantity treated with each regeneration	48 m^3
Resin type	Amberlite IR 410
Regeneration caustic flow rate	2.7 m^3/hr
Amount of 30% Na OH per regeneration	120 kg 90 liters

Water Analysis

	Specification	Measured on 9 May 1977
pH	> 8.5	---
Hydrazine (N_2H_4)	0.1 - 0.2 mg/ℓ	0.1
Phosphate (P_2O_5)	2-5 mg/ℓ	2.5
Silica (SiO_2)	0.3	---

Primary Air Supply

The primary air for each boiler is taken from the pit area by a separate Büttner-Schilde-Haas centrifugal-single-inlet blower rated at 30,000 Nm^3/h (17,655 cfm) at 280 mm (11 in) total pressure. The air is delivered to 3 zones under the grate and the flow to each zone can be controlled from the control room by means of butterfly valves where the operator has an indication of zone air pressure and of valve position.

Secondary Air

The secondary air is also taken from the pit area. Originally the air jets were in both sidewalls, 3 horizontal groups of 6 jets each located approximately one meter (3.28 ft) above the sloping grate. However, as discussed earlier in the section on Furnace Wall, the manufacturer concluded that a principal cause of early failure of 9 tubes in the first open boiler pass was the corrosive action of very hot reducing gases adjacent to those tubes. Also, the sidewall jets appeared to encourage accumulation of slag on the walls. In an effort to achieve better mixing of air and gases the secondary air system was converted in 1974 to front-wall and rear-wall jets, all 64 mm (2.5 in) dia jets. There are 15 jets in the front refractory arch which enter the furnace at an angle of about 45 degrees directly above the first grate section. Figure 2-14 shows the 15 jets on the back wall. The blower supplying these rear jets has a capacity of 9000 Nm^3/h (5292 cfm) at a pressure of 400 mm (15.7 in) water. The jets in the front of the furnace are supplied by a blower having a capacity of 6000 Nm^3/h (3528 cfm) at 500 mm (19.7 in) water. The flow rate to each set of jets can be modulated from the control room by means of butterfly valves. The revised jet arrangement has been so satisfactory that the manufacturer expects to utilize only front and rear wall secondary air jets in future designs.

FIGURE 2-14. SECONDARY AIR JETS IN THE REAR WALL
(Battelle Photo)

CO-FIRING EQUIPMENT

Figure 2-15 shows one of the 2 Elco air-atomizing oil burners which are mounted at the side of each furnace toward the rear. (Figure 2-16 shows the effect of a similar sidewall burner at a hospital waste incinerator in Cologne, W. Germany.) These burners are for the purpose of firing waste oil when available. About 50 percent of the waste oil comes from automotive service stations and 50 percent from industry. This includes some oil emulsions.

The waste oil is first received into a large heated concrete settling tank where it is heated by a heating coil to 50 C (122 F) and held for 3 days to allow solids to settle. From this tank it passes through a fine mesh filter to a daily tank from which it is fired at varying rates up to a maximum of 800 kg/hr (1761 lb/hr) per boiler. The filter must be cleaned every 2 or 3 months.

Plant practice is to reserve the waste oil for firing when the refuse is wet or to dispose of the oil when all oil-storage space is filled. Also, at mid-day when the highest revenue can be realized from the sale of electricity the waste oil may be used. When firing oil both burners on opposite sides of each furnace are used. The burners require little maintenance but are inspected and cleaned every 2 months. They employ light oil for a pilot flame. Some difficulty has been encountered with flotable substances that accumulate at the top of the waste oil settling tank.

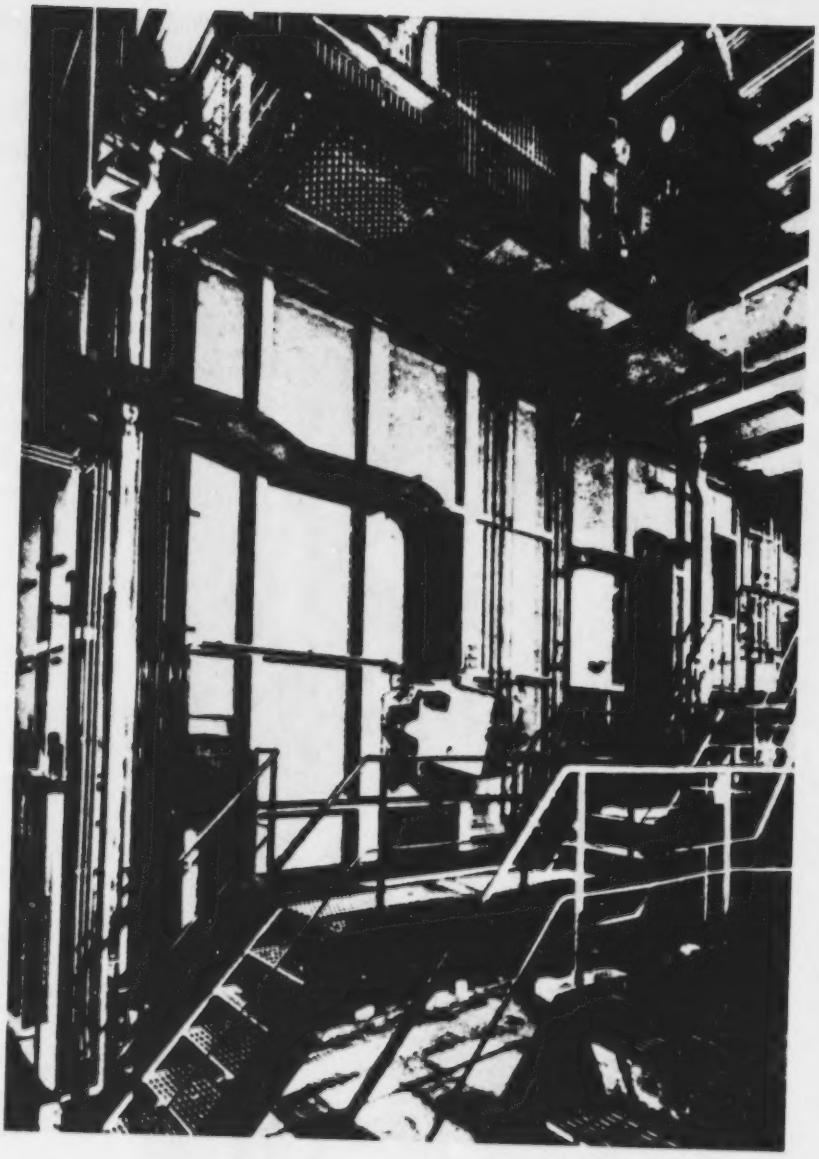

FIGURE 2-15. OIL BURNER ON SIDE OF AND TOWARD REAR OF FURNACE FOR FIRING OF WASTE OIL (Courtesy of Widmer & Ernst)

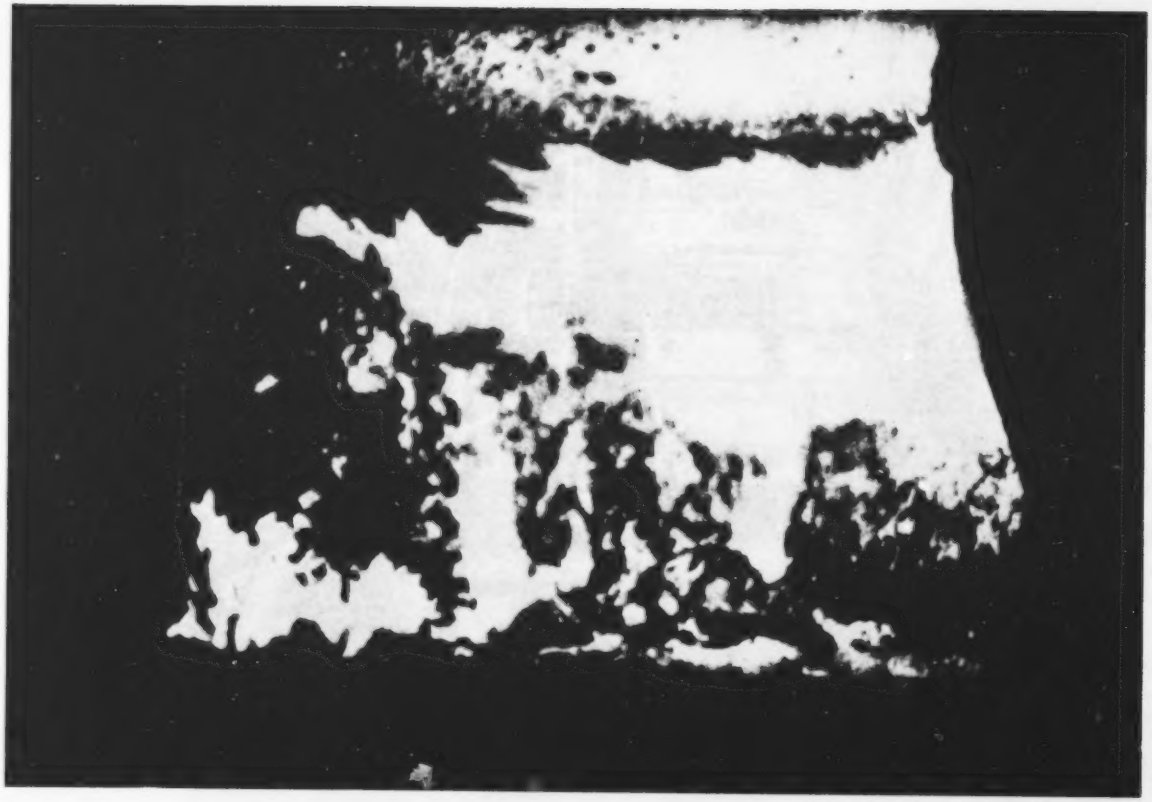

FIGURE 2-16. COLOGNE, W. GERMANY HOSPITAL WASTE INCINERATOR WITH SIDEWALL OIL BURNER (EPA Photograph)

Tertiary Air

Both furnaces are in process of being modified to incorporate sidewall air cooling in the lower portion of the furnace. Figure 2-17 shows the planned arrangement of 8.5 m^2 (91 ft^2) of air-cooled cast iron blocks to be installed on both sidewalls above the grate. The total air supplied to the blocks will be 6500 Nm^3/h (3825 cfm) at a pressure of 190 mm (7.5 in) water. Figure 2-18 shows the air flow pattern which cools the blocks which hang loosely on an air-cooled supporting framework. A Widmer & Ernst photograph (Figure 2-19) shows a man applying the blocks to the sidewalls in an European facility. Finally, Figure 2-20 shows the non-adhering results of a similar furnace.

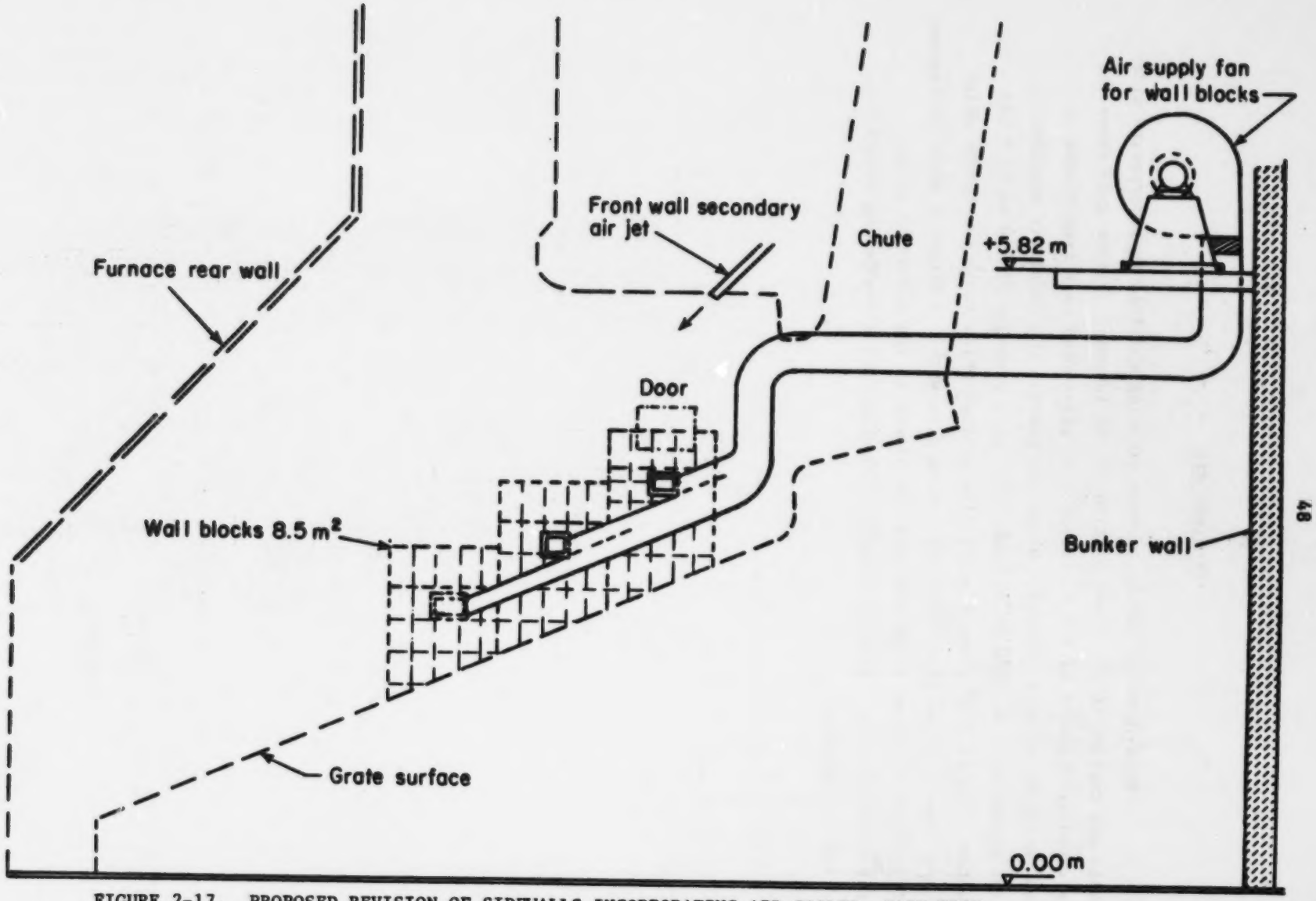

FIGURE 2-17. PROPOSED REVISION OF SIDEWALLS INCORPORATING AIR-COOLED, CAST-IRON, KUNSTLER BLOCKS (Courtesy Widmer & Ernst) from drawing No. 202076 Dated 9-4-76.

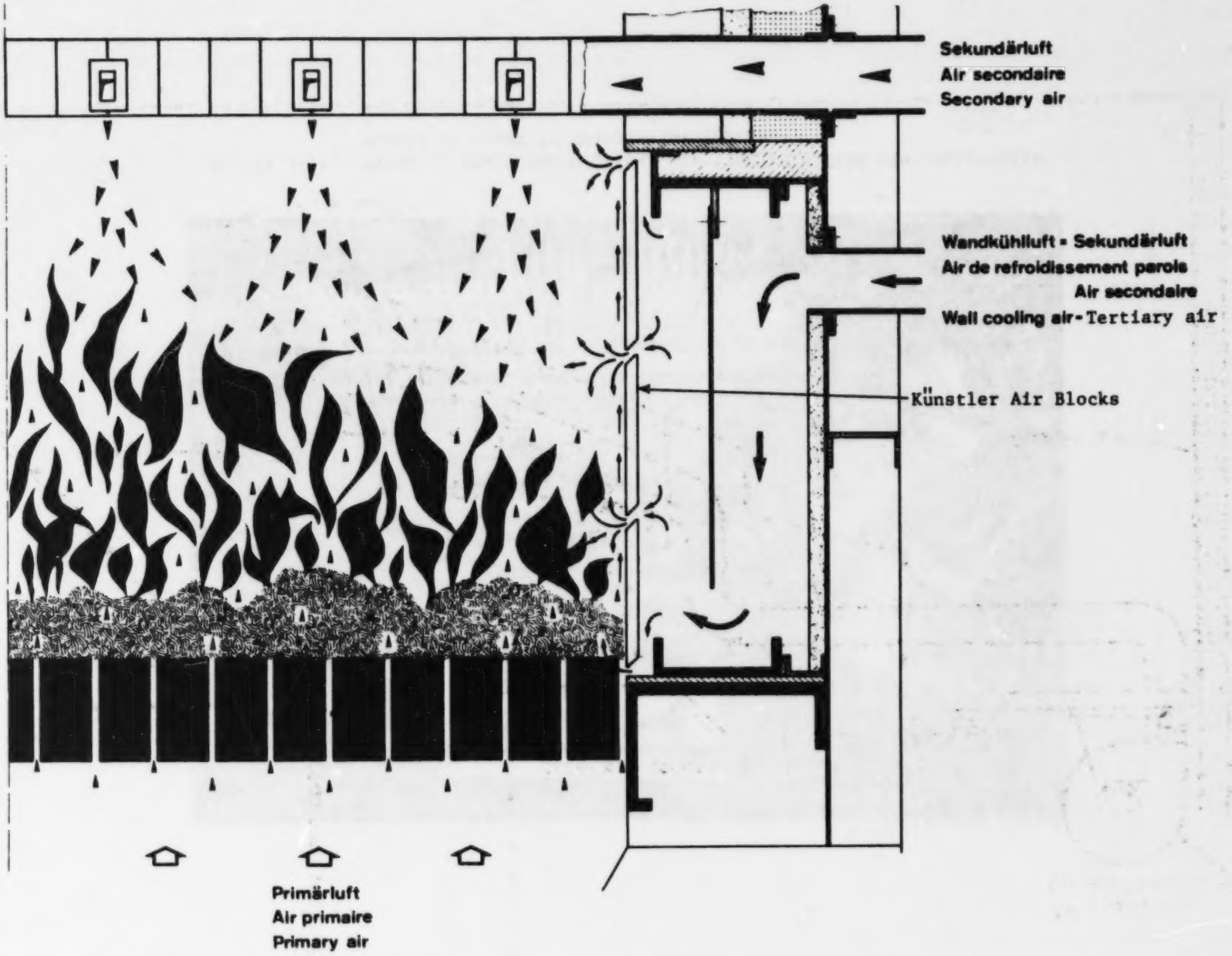

FIGURE 2-18. SKETCH OF AIR FLOWS TO FURNACE (Courtesy of Widmer + Ernst)

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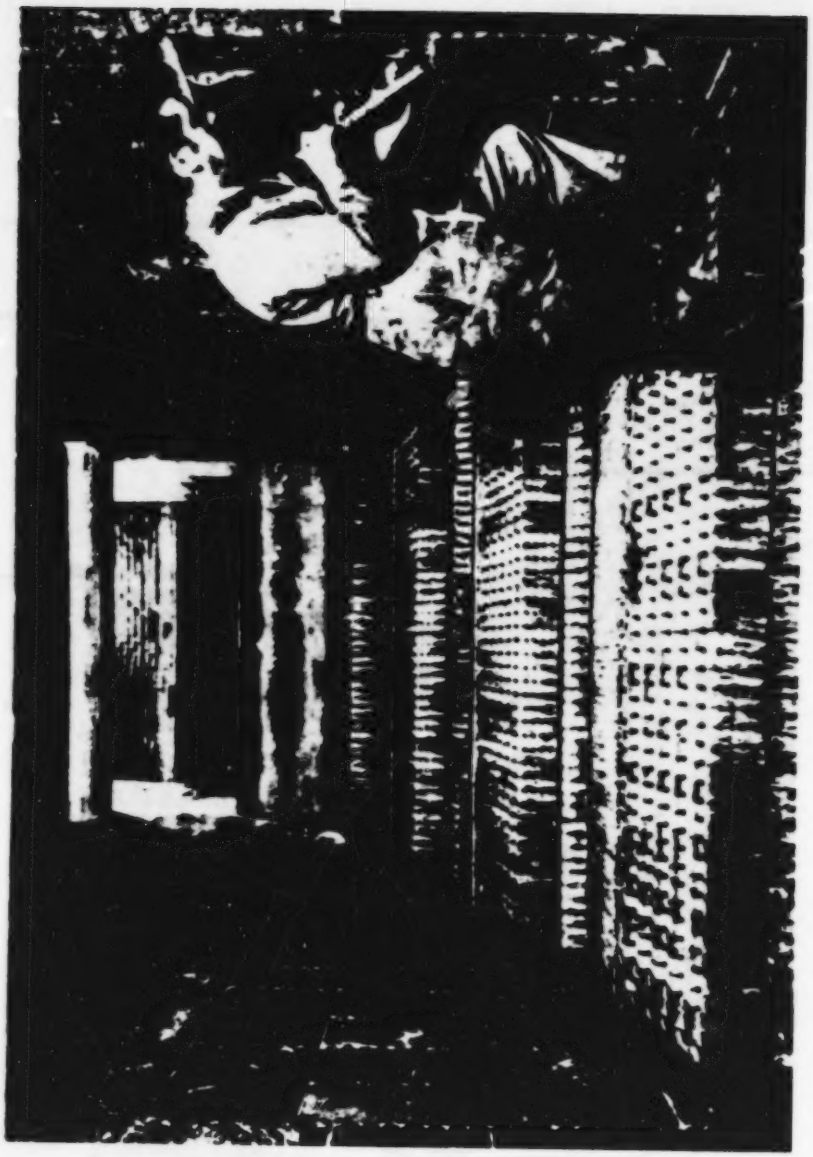

FIGURE 2-19. WIDMER & ERNST PHOTO OF MAN APPLYING KUENSTLER AIR-COLLED WALL BLOCKS AT PLANT IN TRIMMIS SWITZERLAND

FIGURE 2-20. WALL OF FURNACE NO. 1 AT BADEN-BRUGG MODIFIED WITH AIR-COOLED WALL BLOCKS (Licensed by Kuenstler of Zurich) (Battelle Photo)

Energy Utilization Equipment

The energy from this plant is used in the form of electricity used by the regional power system, process steam for the adjacent industrial waste treatment plant, Fairtec, and hot water for plant heating and for heating of the adjacent sewage treatment plant. The electricity is generated in a 6500 KVA Brown-Boveri turbogenerator which consumes a maximum of 25 tonnes/h (55,000 lb/h) of steam at 40 atm (573 psig) and 400 C (725 F). Its effective output is 5.2 mw. Its specific steam consumption is approximately 4.8 kg/kw-hr (10.6 lb/kw-hr). The condenser is cooled by river water. The condenser is cleaned once every 3 months. Process steam is extracted at 1.5 bar (20 psig) and 205 C (400 F). Heating water is supplied at 70 C to 90 C (160 to 198 F). All of the condensate is returned from the waste processing plant.

This summer it is planned to dismantle and reblade the turbine to achieve increased power output from a higher rate of steam flow.

Figure 2-21 shows the scheme for heat and electricity distribution.

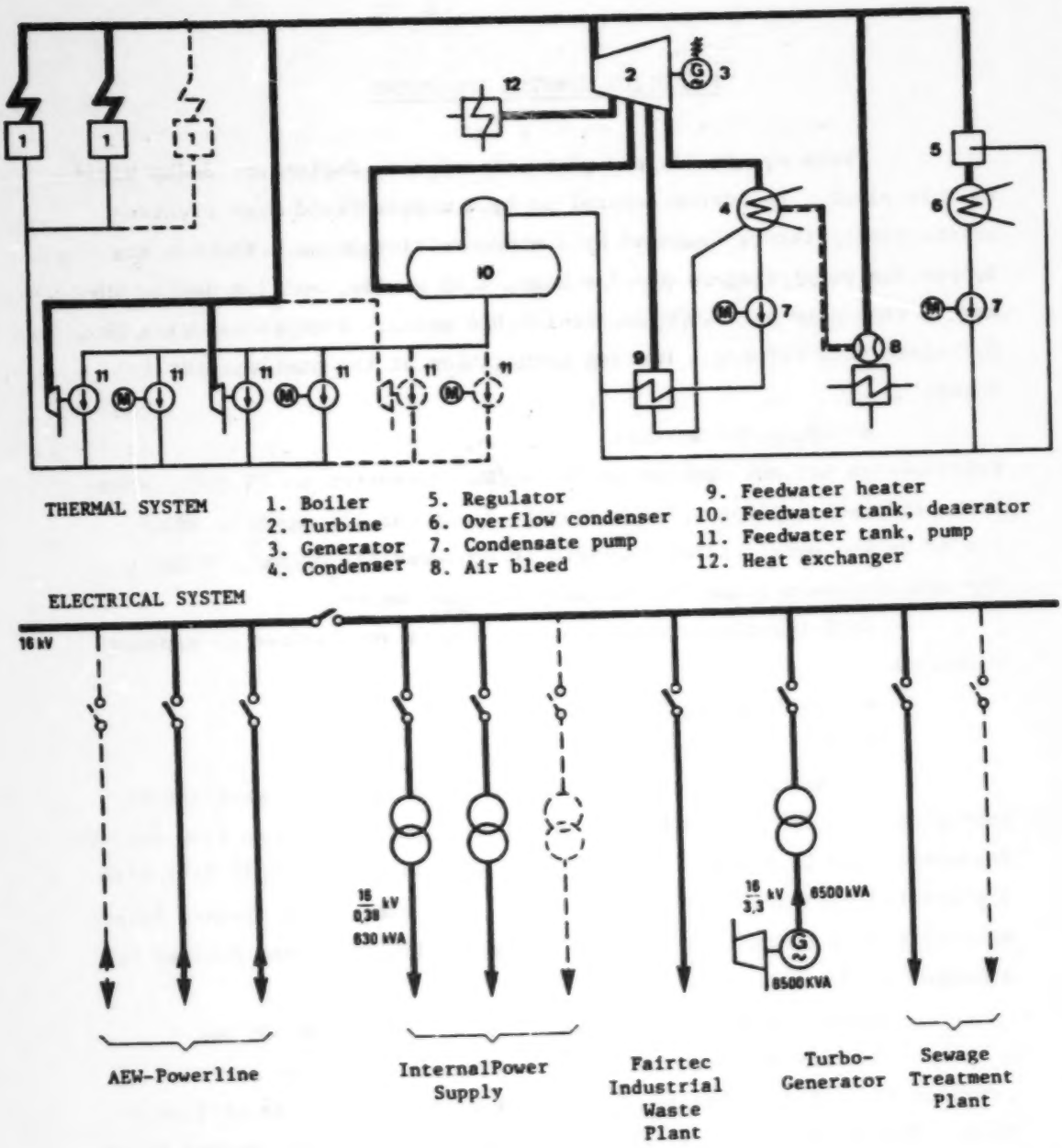

FIGURE 2-21. SCHEMATIC DIAGRAM OF THERMAL AND ELECTRICAL SYSTEMS (Courtesy of Widmer & Ernst)

POLLUTION CONTROL EQUIPMENT

There was no visible plume at any time during our 3-day visit to this plant. Pollution control is by 2 single-field Elex electrostatic precipitators followed by 2 stage multicyclones. Without the hopper the precipitators are 7 m high, 4.45 m wide, and 7 m deep. They have a flow rate of 64,000 Nm^3/hr (37,664 scfm). Average velocity is 0.7 m/sec (2.3 ft/sec). The gas composition at the precipitator is about:

- CO_2 - 6-7 percent

Particulates are now limited to 100 mg/Nm^3 corrected to 7% CO^2. When this plant was designed, the allowable limit was 150 mg/Nm^3. When tested by the manufacturer in 1971, it achieved 111 mg/Nm^3. With the multi-cyclone alone the emission was 1100 mg/Nm^3.

In Switzerland, waste-burning plants are limited to gaseous emissions of:

- SO_2 - 300 mg/Nm^3
- HCl - 500 mg/Nm^3

The precipitators and their duct configuration were tested beforehand by Elex in small water model to assure a uniform flow pattern. Residence time is 5.9 sec. Total plate area is 612 m^2 (6587 ft^2) with a projected area of 952 m^2 (10,247 ft^3). The plates are cleaned intermittently by a bottom rapper. The charging electrodes are cleaned by a rapper at the top.

Output capacity is 55 KVA at 55,000 volts and 506 ma.

The fly ash hoppers are approximately 50 degree inverted pyramids electrically heated and covered with 10 cm (4 in) of insulation. The collected ash is removed continuously by star feeders which discharge directly downward into the main residue quench tank.

The precipitator was guaranteed to achieve 97 percent efficiency. Assuming an inlet loading of 5 grams/Nm^3 the measured efficiency was

97.8 percent. However, on 3 brief 40 minute tests on May 25, 1971, the average inlet loading was only 1.846 g/Nm^3, the outlet was 0.111, corresponding to an efficiency of 94.0 percent. The average CO_2 was 7.8 percent.

So far, the precipitator has needed no repairs. It is cleaned once per year when the boiler is cleaned. For personnel protection, the access doors cannot be opened before an 8-multiple key sequence is processed.

To achieve lower particulate emissions from future plants, the manufacturer is considering the use of two-field precipitators.

The prcipitators have suffered no serious corrosion during the normal weekend shutdowns. Initially cracks in the porcelain insulators caused arcing but this was cleared up by replacing them with other ceramic insulators. In 29,000 hrs of operation over 7 years there have been no electrodes nor plates replaced.

Wastewater Discharge

Boiler blowdown and cooling jacket water goes to the residue quench tank from which any overflow goes to the adjacent sewage treatment plant.

Federal regulations limit the temperature rise of river water used for cooling to 6 C (10.8 F). Accordingly the turbo-condenser discharge is diluted with clear effluent from the sewage plant giving an effective temperature rise of one degree celsius.

Stack Construction

The 1.8 m dia (5.9 ft) concrete stack is 80 m (262 ft) tall. It was fabricated by Schilling of Dübendorf. Below the flue gas inlet the chimney lining is acid-resistant refractory. Above it is normal refractory.

Pollution Control Assessment

Since the plant was built the Federal emission limit for particulates has been dropped from 150 mg to 100 mg/Nm^3 at 7% CO_2. However, the stack plume was never visible during our visit and with a busy railroad on one side of the plant and the Limmat river on the other an effect of its emissions would be minute.

All wastewater is treated by the adjacent sewage treatment plant.

The overall appearance of Swiss cities and countryside is very clean. This low environmental pollution level is achieved by a minimum of necessary regulation. New regulations are implemented with cautious deliberation. On the other hand, old regulations are tightened where economically and technologically feasible. For example, in recent years, the particulate emission limit to the atmosphere of 150 mg/Nm^3 corrected to 7 percent CO_2 has been dropped to 100. This new value is equivalent to 0.044 gr/scf. For 5,000 Btu/lb refuse (LHV) (2778 kcal/kg) [11,630 kJ/kg] this amounts to about 0.11 lb/10^6 Btu input (0.616 mg/10^6 kcal) [0.147 mg/kJ].

A Swiss survey of municipal refuse shows that 50 percent of the refuse averages about 6 kg HCl/tonne of waste and that 95 percent of the refuse burned has less than 15 kg HCl/tonne. Potentially, this higher value could result in about 1,700 mgHCl/Nm^3 (0.0014 lb/1000 lb) being discharged to the atmosphere. Actually, an unknown amount will stay in the furnace, precipitator, and residue so probably less than 1,000 mg/Nm^3 (0.0008 lb/1000 lb gas) is emitted. The fact that scrubbers to remove HCl from the hot gases have not been well developed and little deleterious atmospheric concentrations of HCl have been observed leads the government to caution in regulation of this emission. On the other hand, since HCl emissions are obviously undesirable, there has been a 3-4 year effort to encourage the substitution of innocuous plastics for PVC in the Swiss economy. This still leaves the normal NaCl and agricultural chlorine in refuse which constitutes about half of the total amount of chlorine in refuse.

If eventually scrubbers to remove HCl become necessary, the regulatory staff is well aware of their disadvantages:

- Scrubber sludge
- Additional cost
- Corrosion
- Visible wet plume
- Acid wastewater
- Efficiency on fine particulates often low.

Hence, the Swiss concensus is not to require scrubbers unless HCl removal is proven highly necessary. Meanwhile, the PVC content of municipal refuse is being monitored and each plant will be tested for HCl emission about every 2 years.

Noises

This plant, along with the Limmat River railroad track, highway, and hills is surrounded by industry and cultivated fields. It is remote from human habitations and noise has been no problem. According to Swiss regulations, no plant can emit at its boundary noise exceeding:

- 55 db (A) at night
- 65 db (A) in the day
- 80 db (A) peaks.

PERSONNEL AND MANAGEMENT

The plant is owned and operated by the Zweckverband Kehrichtverwertung Baden-Brugg. President of the organization, Dr. Zumbühl, hires the Plant Manager, who in turn, hires the remainder of the staff. The governing board (Vorstand) and council meet about twice per year to make major decisions.

This plant now operates 5 days per week with only 3 operators on each of three shifts plus a standby operator, the Plant Manager, E. Luedi and his assistant. The administrative and maintenance staff works 5 1/2 days (44 hrs) per week. One maintenance worker is full time and 3 others are part time. When not working on maintenance these men can fill in on other jobs. In January 1978 the plant will begin a 7-day week operation. The total plant staff is now 18 and the manager indicated there should be more. The manager is also responsible for the operation of the adjacent sewage plant.

Total wages and salaries for 1976 were 825,163.65 Sw Fr ($332,541). This is an average of $1535 per worker per month. Benefits in addition were 108,475.55 Sw Fr ($43,716) per year. An extensive annual report is prepared with the assistance of local government accountants.

Each of the plant staff receives brief training except the scale operator and custodian. No federal boiler operator's license is required. This plant has a unique source of skilled personnel in that the world headquarters of the Brown-Boveri Co. is located in Baden. Hence three of the current shift foremen have had extensive prior experience in building and assembling heavy power-generating machinery.

New workers are first assigned to the assistant plant manager for 3 or 4 days per week to become familiar with the overall plant. Then they are gradually transferred to work alongside the current operator on the job to which they will be assigned. After 4 or 5 weeks they are expected to be able to handle the task alone except for some assistance during start-up and shut-down.

The Swiss Federation of Large Boiler Operators provides lectures and training and also issues certificates for general boiler operation. The Widmer + Ernst Co. has provided operation and maintenance instructions on each plant component.

Energy Marketing

The only energy export from this plant is as follows:

Electricity to:

1. Sewage treatment plant
2. Aargau Elektriztatswerk (AEW)

Steam to:

1. Fairtec, industrial waste processing plant

Hot water to:

1. Sewage treatment plant.

A long range plan has considered the possibilities for using turbine exhaust steam for district heating in Baden, possibly tied in with waste heat from a future nuclear plant.

The sewage plant receives electricity at the rate of 19,500 to 32,000 kw hr per week.

The electricity sold to the local network, AEW, derives a variable revenue depending on time of day and depending on how much hydropower is available to the network. In the winter hydropower is reduced because the highland snowfall does not melt. In the summer, Switzerland as a whole, has excess hydropower and exports electricity. The range of rates paid to the Baden-Brugg plant is as follows; Sw Fr per kw hr (US cents/kw hr):

	Winter	Summer
High	0.045 (1.8)	0.030 (1.2)
Low	0.028 (1.1)	0.018 (0.7)

ECONOMICS

Capital Investment

In 1970 this plant cost 16,400,000 Sw Fr. (the equivalent of $6,560,000 U.S. in 1977$). This is $32,800 per tonne-day capacity. The first cost included one million Swiss Francs for 2 electrostatic precipitators.

Operating Costs

Table 2-4 is from the Statistical Statement in the 1976 Annual Report showing the plant operation for the years 1975-1976 including operating costs. For 1976, the net operating cost was 15.94 Sw Fr/tonne. Other costs were added as follows:

Operation	15.94 Sw Fr/tonne	$5.83/ton
Capital	22.60	8.27
Cash reserve	11.69	4.27
Average overall Cost	50.23	18.37
Cost per person-year	15.03	5.50

Total operating cost was made up as follows:

Operation and maintenance	1,408,566.70 Sw Fr	$567,652.38
Interest and debt reduction	942,370.30	379,775.23
Repairs	487,362.65	196,407.15
Total Annual Cost 1976	2,838,299.65	$1,143,834.76

However, for a population of 140,000 this total corresponds to $8.17 per person instead of the $5.50 shown in Table 2-4.

TABLE 2-4. PLANT INCOME FOR 1975 and 1976 (FROM STATISTICAL STATEMENT IN 1976 ANNUAL REPORT)

Income from electricity sold to AEW	Fr.	514,041.80	422,716.--
Income per KWh	Rp./kWh	3.89	3.42
Income per tonne waste	Fr./t	13.02	10.89
Operating cost, principal (1)(2)(3)	Fr./t	32.29	31.96
Operating cost, net (1)(2)(3)	Fr./t	15.94	19.03
Capital cost	Fr./t	22.60	23.22
Capital cost (1)	%	40.08	40.88
Reserve	Fr./t	11.69	8.88
Average cost per tonne	Fr./t	50.23	51.13
Cost per inhabitant-year	Fr./person-year	15.03	14.82

(1) without cash reserve
(2) without capital cost
(3) without electricity for sewage plant from AEW
* 1975: 5 day work week
1976: 5 1/2 day work week

FINANCE

The total cost of the plant 16.5 x 10^6 SwFr ($6.65 x 10^6) was financed by a regular bank loan of 10.4 x 10^6 SwFr plus joint financing of the 6.1 x 10^6 SwFr remainder by Federal and Cantonal grants in the amount of 2.5 x 10^6 SwFr from the Federal Government and 3.5 x 10^6 SwFr by the canton of Aargau.

The interest on the debt ranges from 5.25 to 6 percent and the loan is tax exempt. As of 1977, the original loan of 10.4 x 10^6 SwFr had been reduced to 6.6 x 10^6 SwFr.

*U.S. GOVERNMENT PRINTING OFFICE: 1979 633-007/5008 1-3